US009553359B2

(12) **United States Patent**
Kagaya

(10) **Patent No.: US 9,553,359 B2**
(45) **Date of Patent: Jan. 24, 2017**

(54) **ANTENNA APPARATUS**

(71) Applicant: **ASAHI GLASS COMPANY, LIMITED**, Tokyo (JP)

(72) Inventor: **Osamu Kagaya**, Tokyo (JP)

(73) Assignee: **ASAHI GLASS COMPANY, LIMITED**, Tokyo (JP)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 454 days.

(21) Appl. No.: **13/929,659**

(22) Filed: **Jun. 27, 2013**

(65) **Prior Publication Data**

US 2013/0285861 A1 Oct. 31, 2013

Related U.S. Application Data

(63) Continuation of application No. PCT/JP2011/079930, filed on Dec. 22, 2011.

(30) **Foreign Application Priority Data**

Dec. 28, 2010 (JP) 2010-293249

(51) **Int. Cl.**
H01Q 1/32 (2006.01)
H01Q 1/12 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***H01Q 1/3291*** (2013.01); ***H01Q 1/1271*** (2013.01); ***H01Q 1/1285*** (2013.01); ***H01Q 13/16*** (2013.01); ***H01Q 13/18*** (2013.01)

(58) **Field of Classification Search**
CPC H01Q 1/3291; H01Q 1/1271
(Continued)

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,012,255 A * 4/1991 Becker H01Q 1/1278 343/704
5,124,714 A 6/1992 Harada
(Continued)

FOREIGN PATENT DOCUMENTS

EP 0 561 272 A1 9/1993
EP 0 961 342 A2 12/1999
(Continued)

OTHER PUBLICATIONS

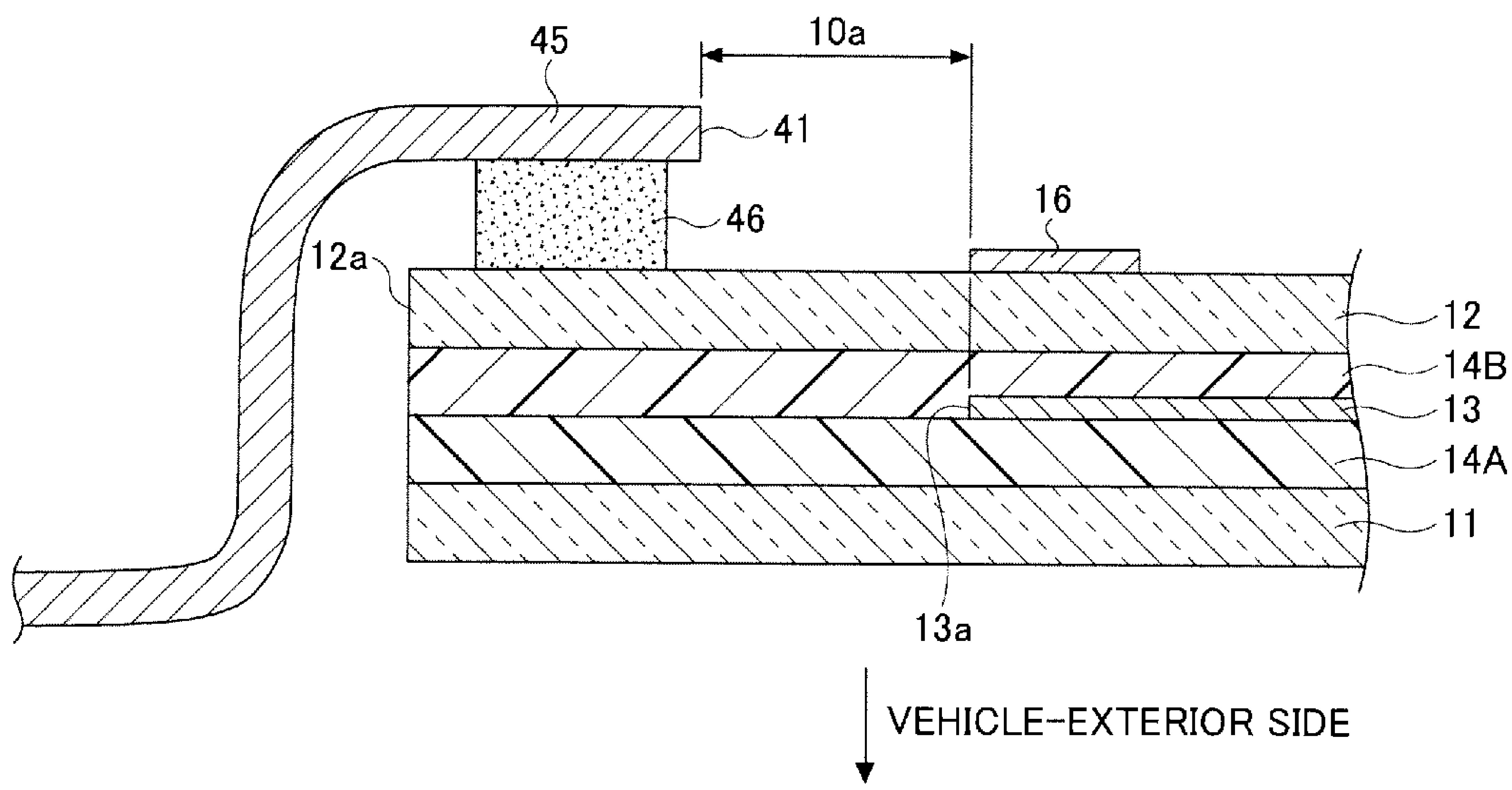
International Search Report PCT/JP2011/079930 dated Apr. 3, 2012.

Primary Examiner — Dameon E Levi
Assistant Examiner — Walter Davis
(74) *Attorney, Agent, or Firm* — Foley & Lardner LLP

(57) **ABSTRACT**

An antenna apparatus includes a glass plate that is fixed to a flange of a vehicle body at a window opening portion of the vehicle body; a dielectric material; a conductive film provided between the glass plate and the dielectric material; and a monopolar feeding portion provided on the dielectric material at a surface opposite to a glass plate side and at a position capable of being capacitively coupled to the conductive film, the antenna apparatus being configured such that a clearance between an end portion of the flange of the vehicle body and an outer edge of the conductive film functions as a slot antenna, the conductive film being provided with a notch having one end as an open end at the outer edge of the conductive film in the vicinity of the feeding portion.

8 Claims, 9 Drawing Sheets



(51) **Int. Cl.**
H01Q 13/16 (2006.01)
H01Q 13/18 (2006.01)

(58) **Field of Classification Search**
USPC 343/712, 711, 704
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

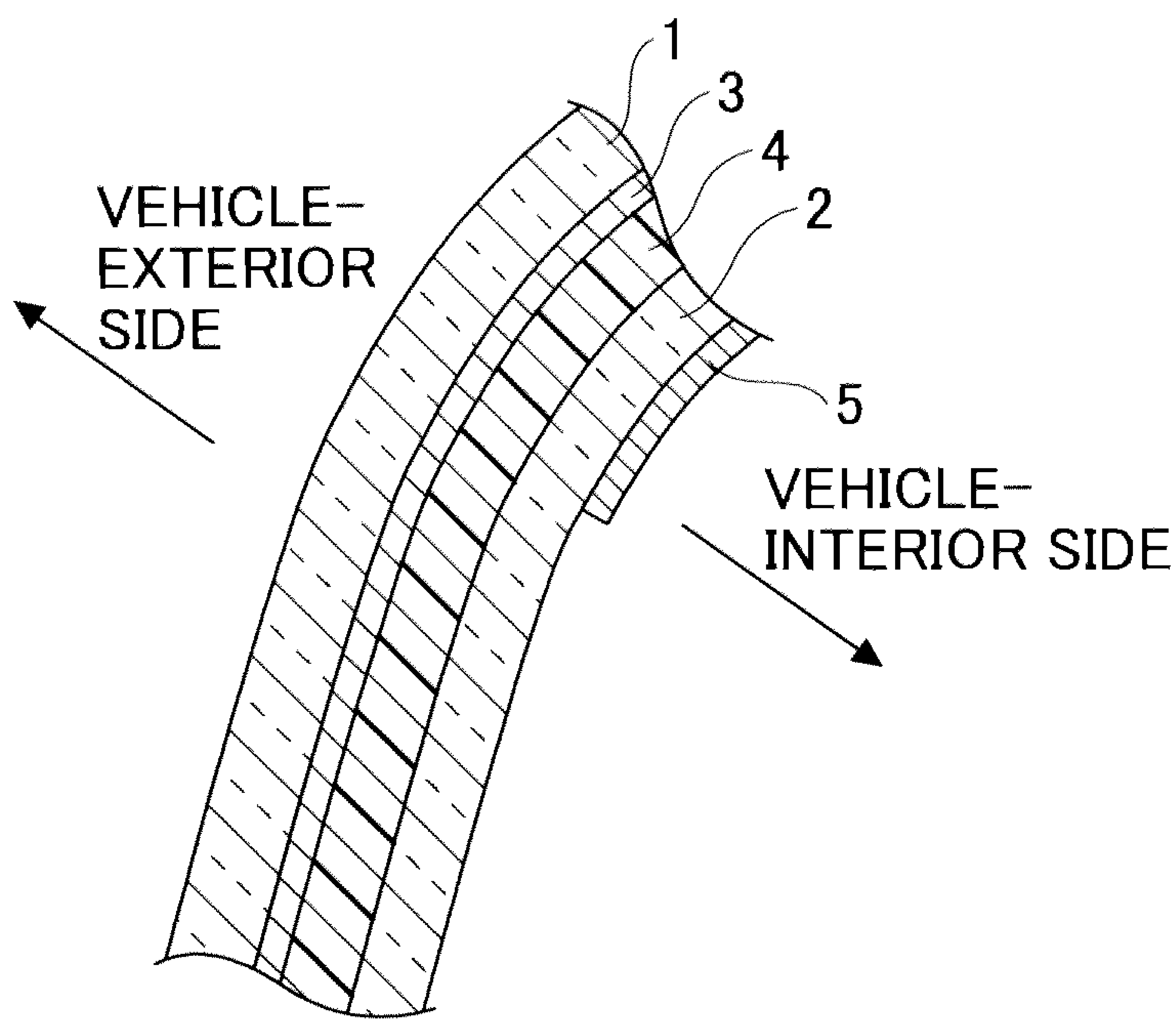
5,355,144	A	10/1994	Walton et al.	
5,831,580	A	11/1998	Taniguchi et al.	
5,898,407	A *	4/1999	Paulus	B32B 17/10 343/713
6,320,276	B1	11/2001	Sauer	
7,190,316	B2 *	3/2007	Yegin	H01Q 1/1285 343/700 MS
2004/0070540	A1	4/2004	Wang et al.	
2005/0190112	A1	9/2005	Thudor et al.	
2006/0017632	A1	1/2006	Funatsu	
2006/0202898	A1	9/2006	Li et al.	
2012/0154229	A1 *	6/2012	Kagaya	H01Q 13/10 343/713

FOREIGN PATENT DOCUMENTS

EP	1 580 839	A1	9/2005
JP	6-45817	A	2/1994
JP	H07-235821	A	9/1995
JP	9-175166		7/1997
JP	H11-163625	A	6/1999
JP	2000-59123		2/2000
JP	2005-012587		1/2005
JP	2005-278159	A	10/2005
JP	2006-525691	A	11/2006
JP	2010-263646	A	11/2010

* cited by examiner

FIG.1



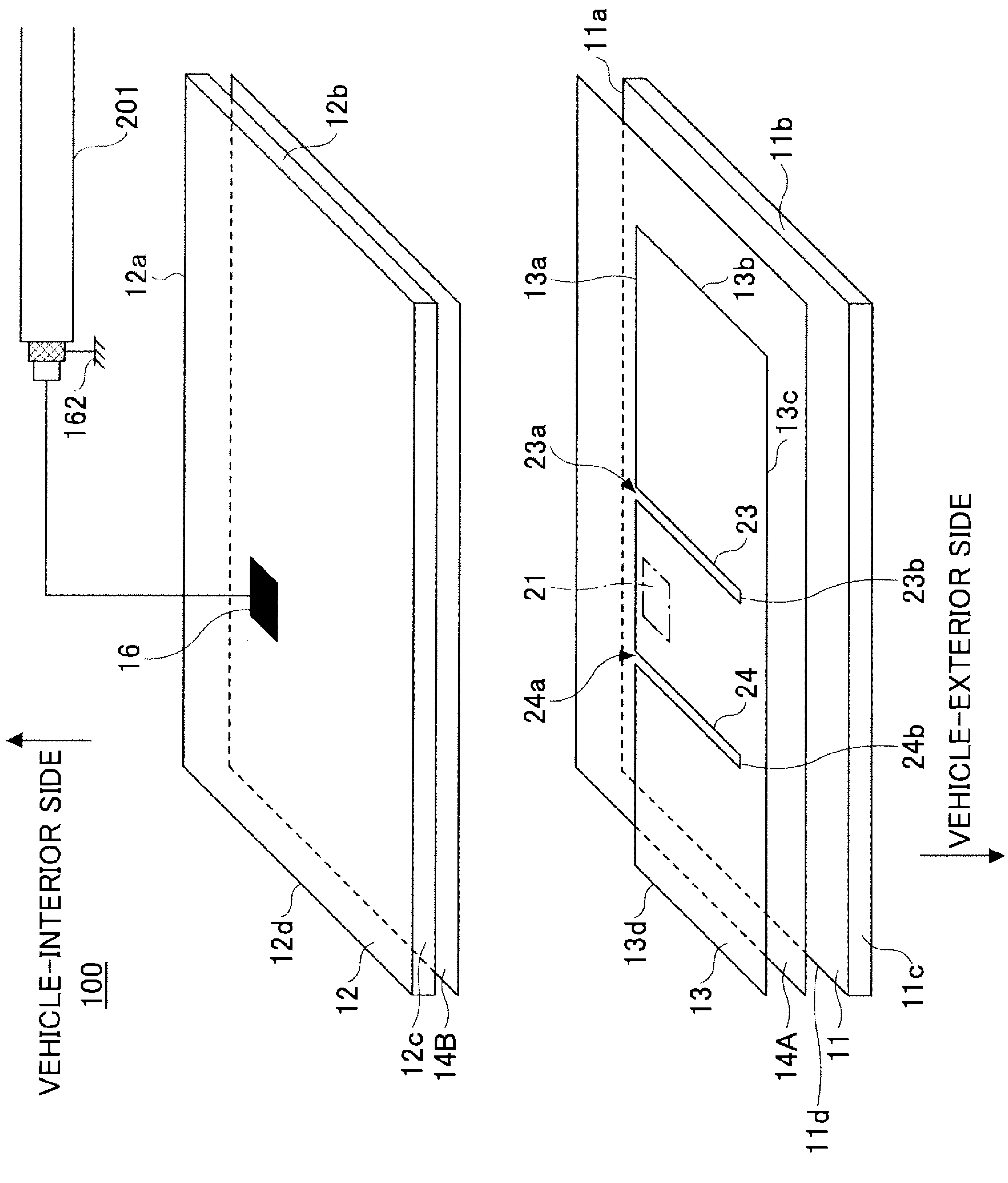

VEHICLE-INTERIOR SIDE
100
201
162
12a
12b
16
12d
12
12c
14B
11a
11b
13a
13b
13c
23a
23
21
23b
24a
24
24b
13d
13
14A
11
11d
11c
VEHICLE-EXTERIOR SIDE

FIG.2

FIG.3

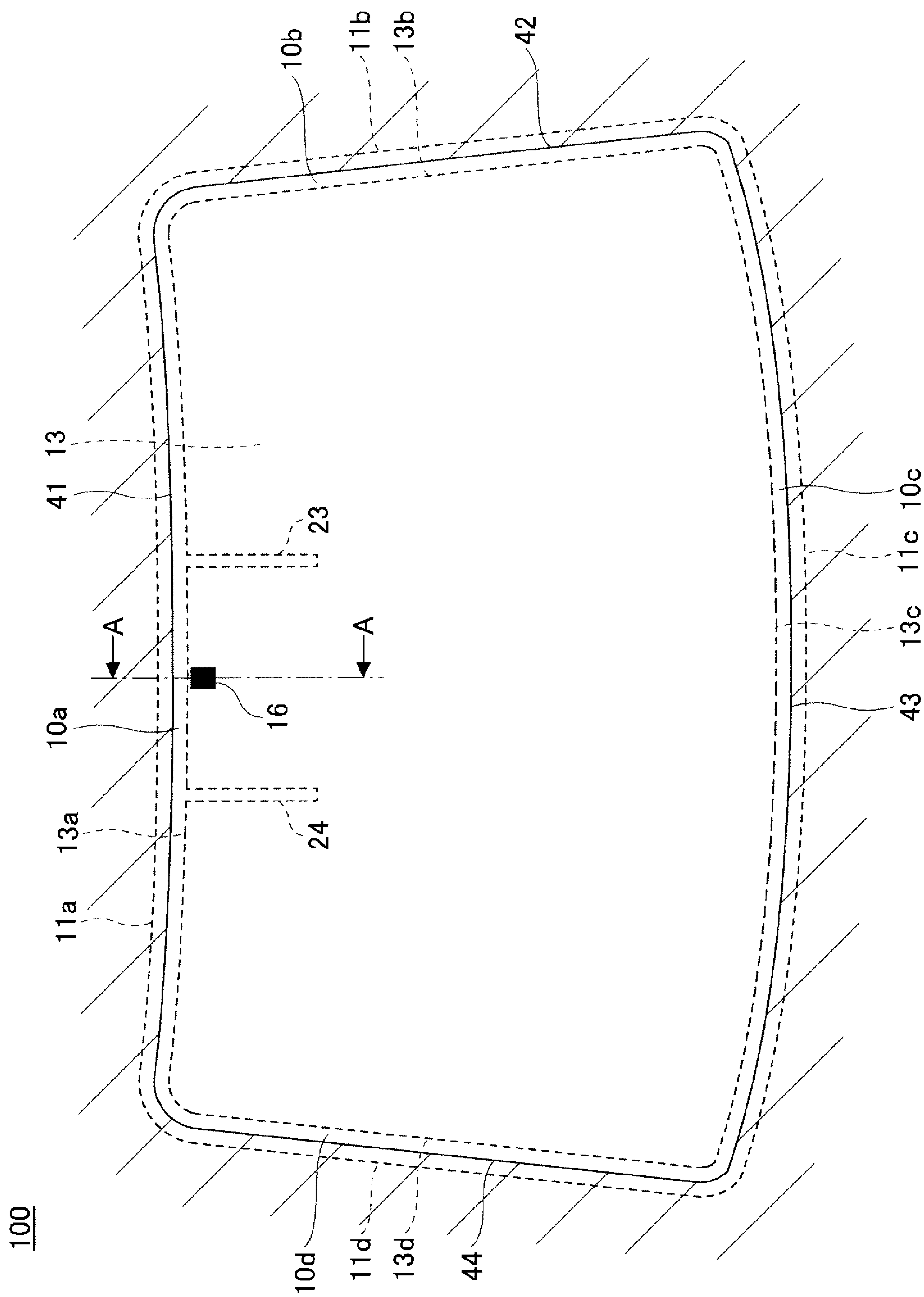

100
10a
10b
10c
10d
11a
11b
11c
11d
13
13a
13b
13c
13d
16
23
24
41
42
43
44
A
A

FIG.4

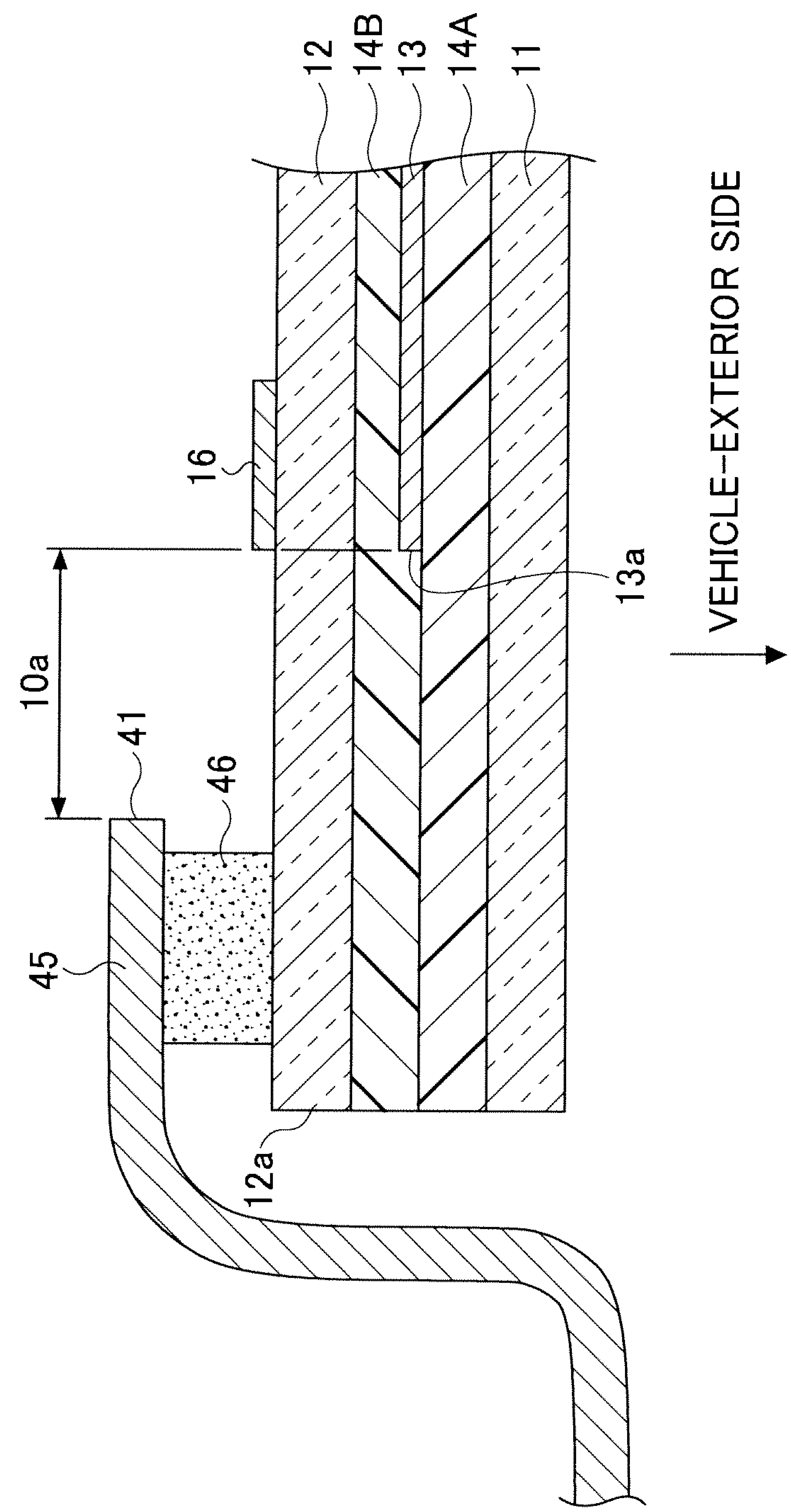


FIG.5A

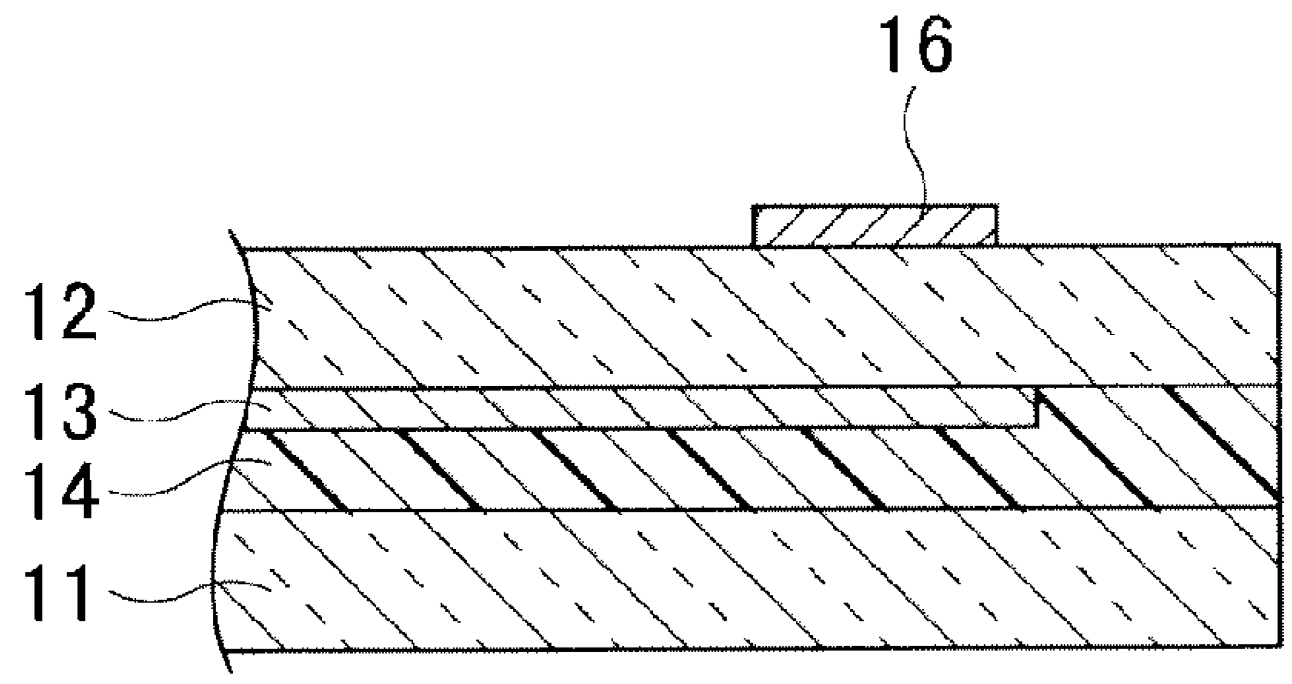


FIG.5B

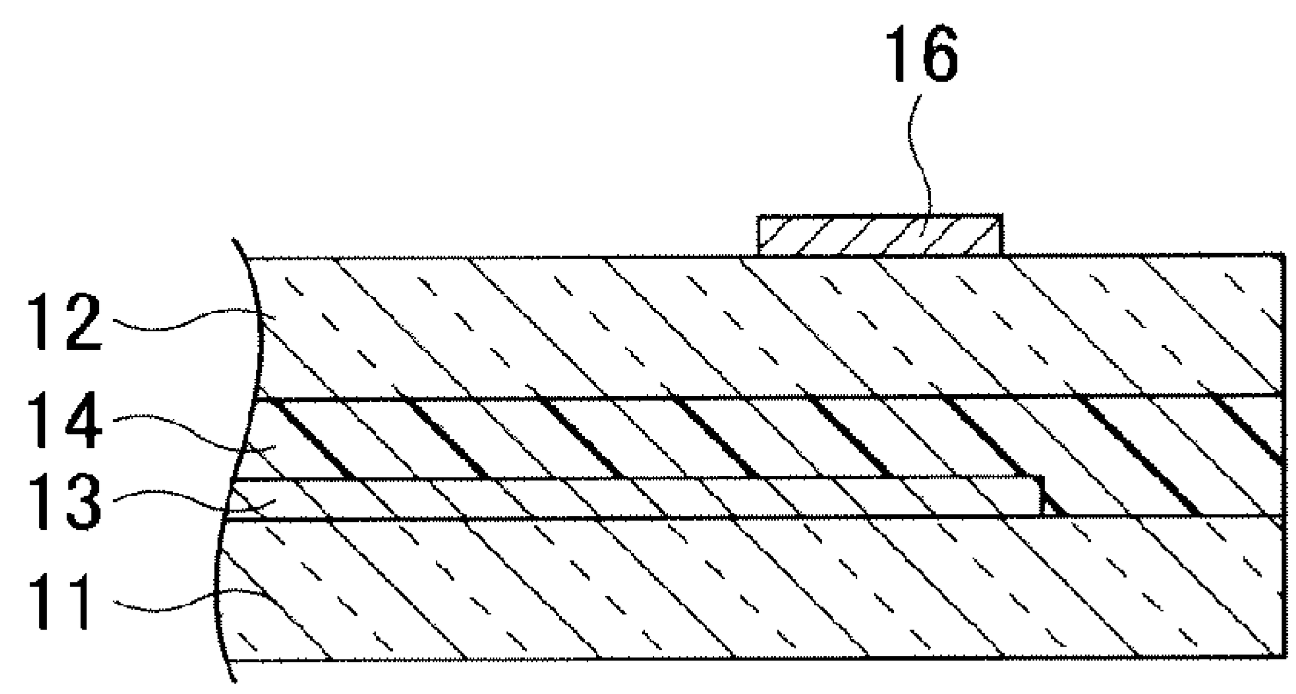


FIG.5C

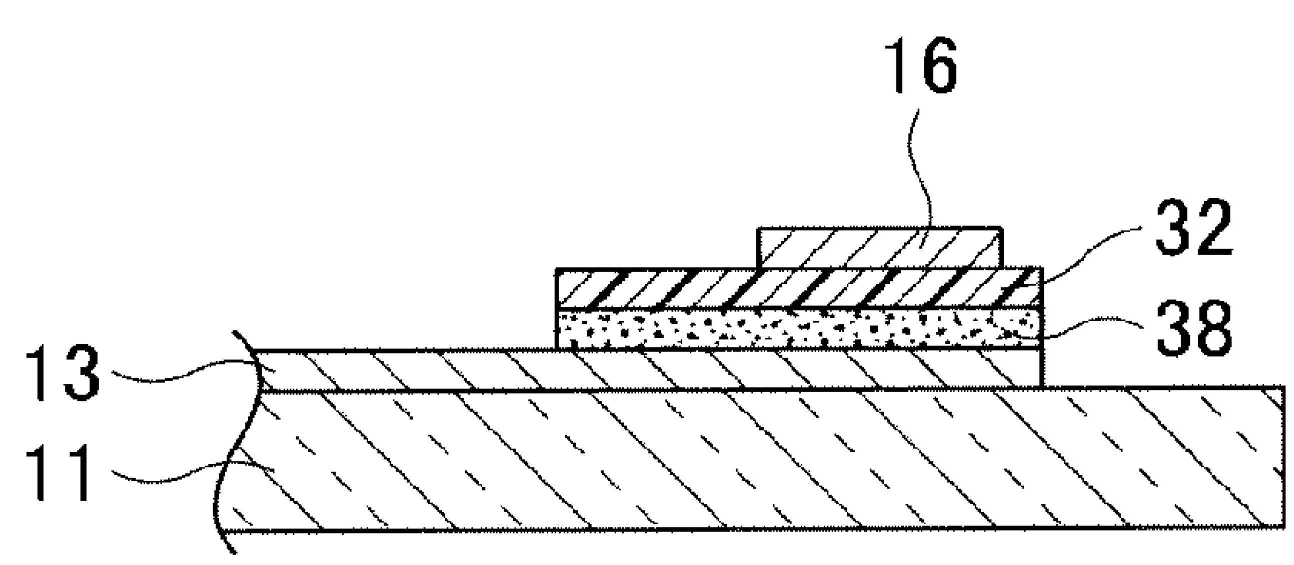


FIG.5D

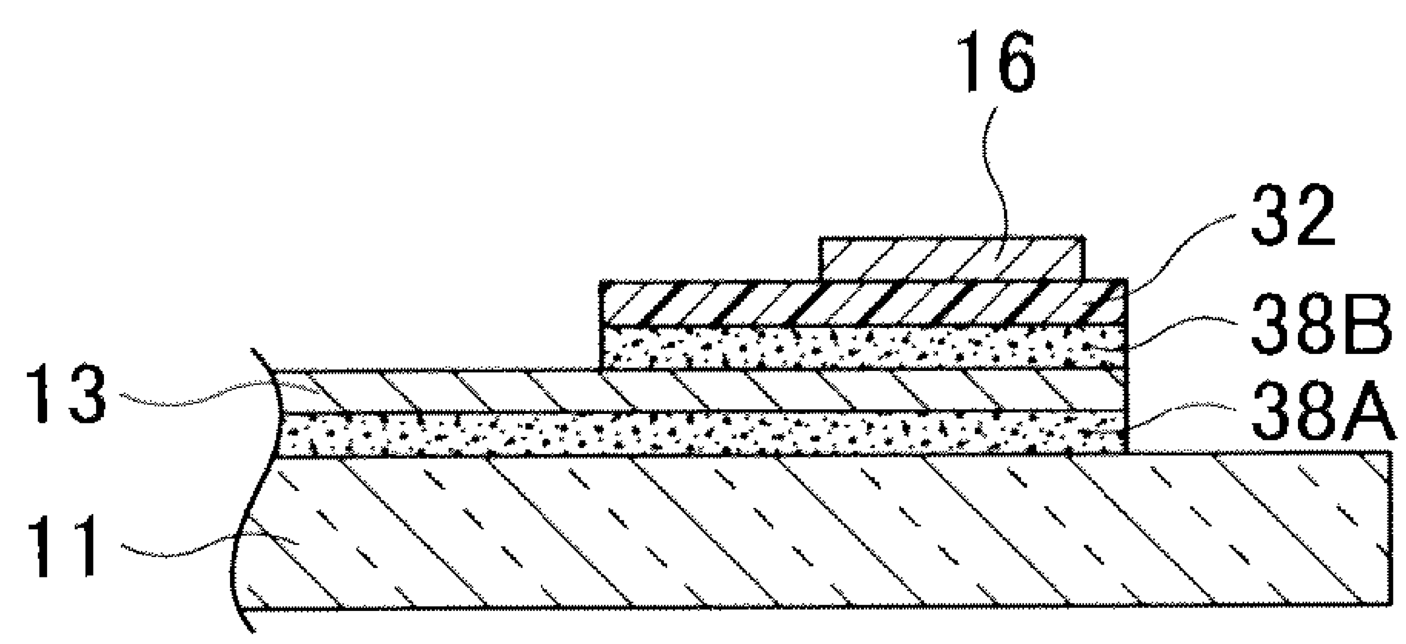


FIG.6A

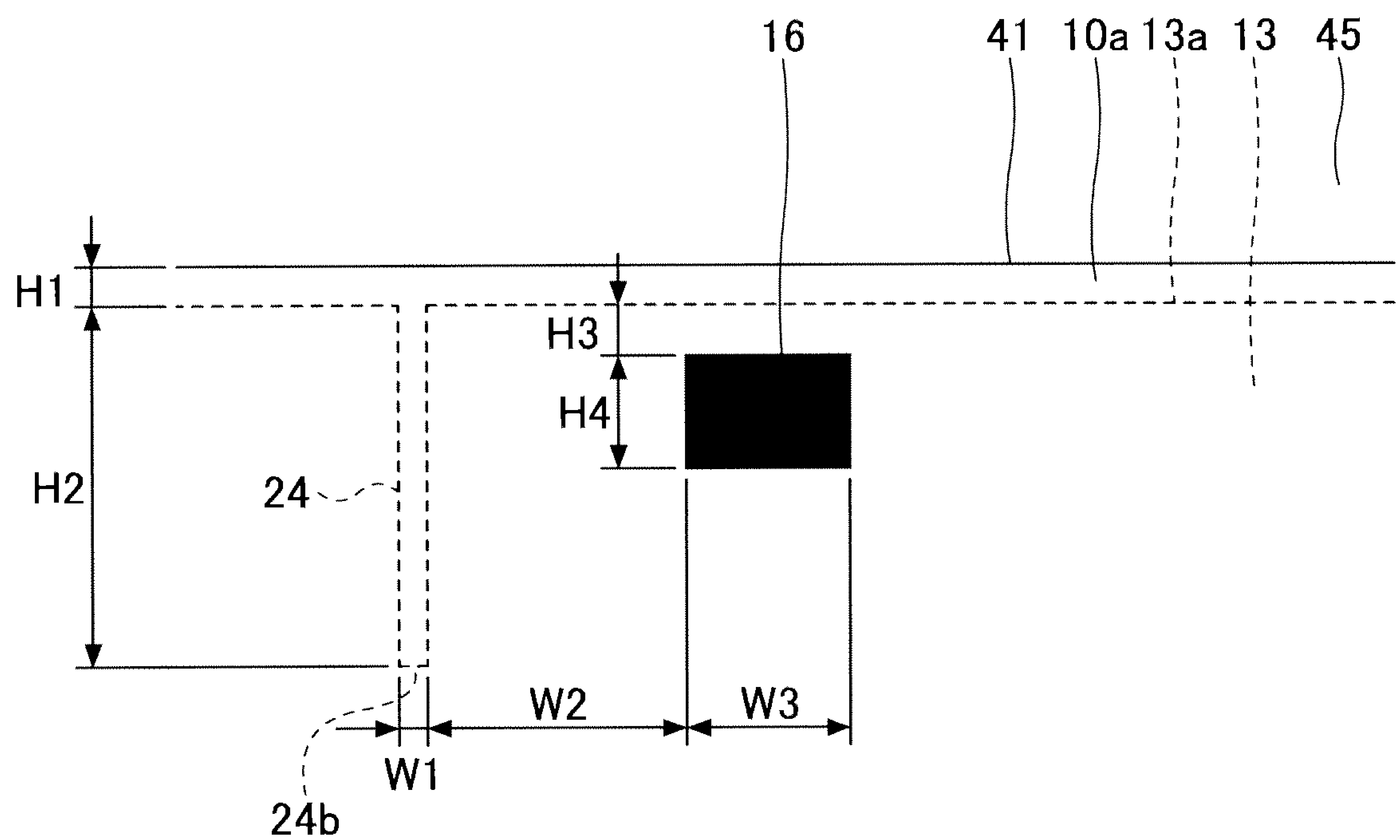


FIG.6B

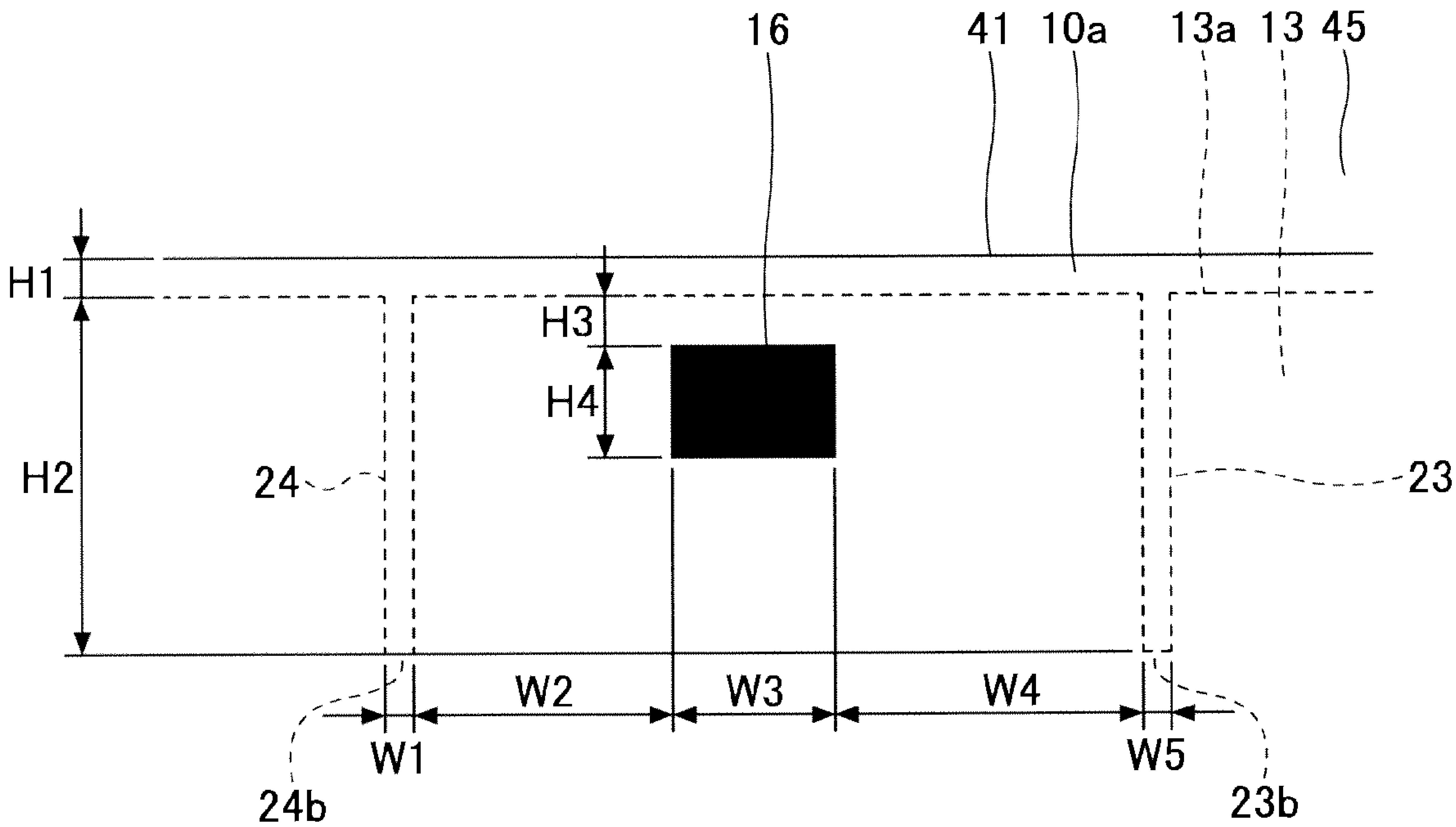


FIG.7

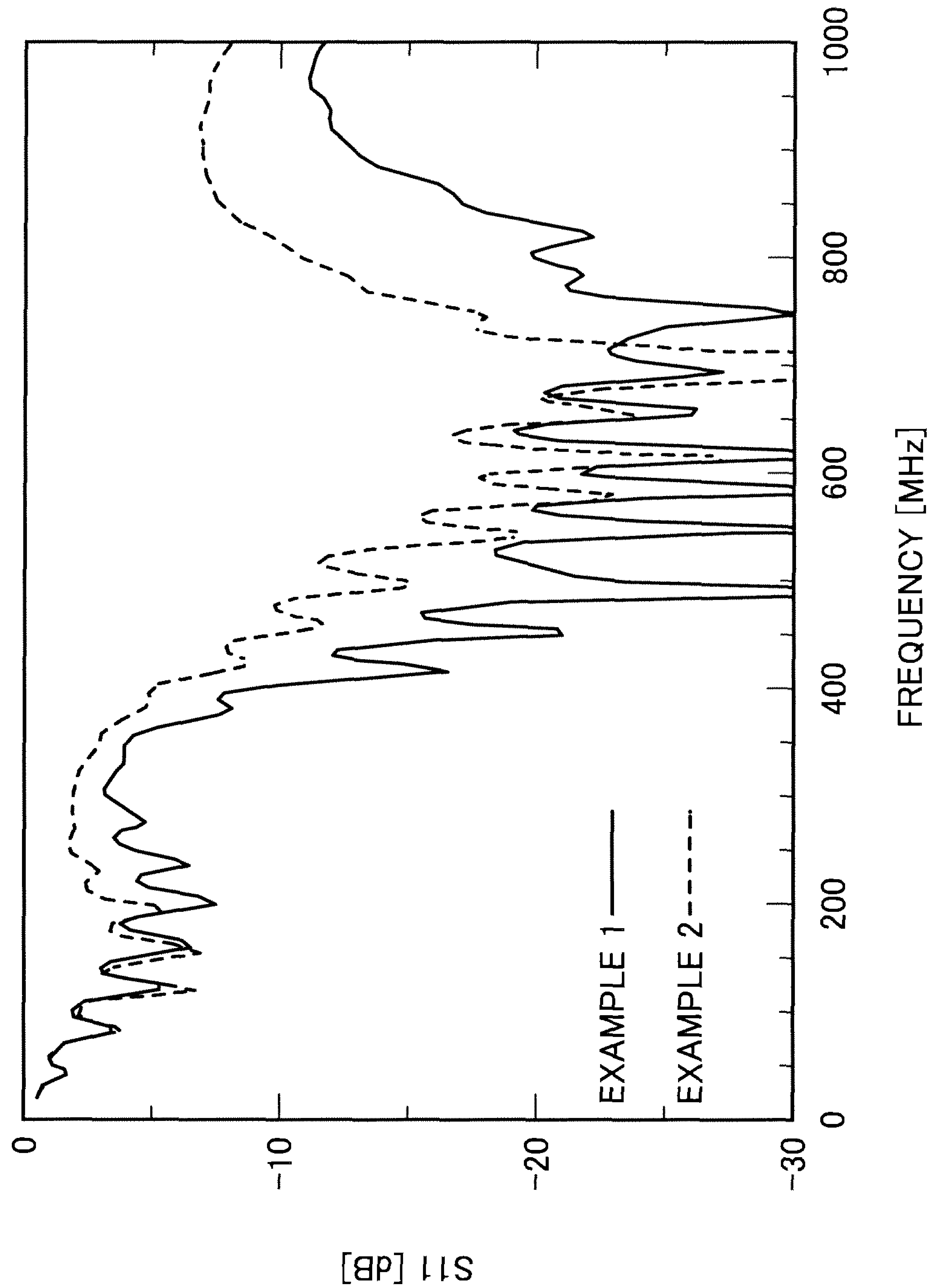
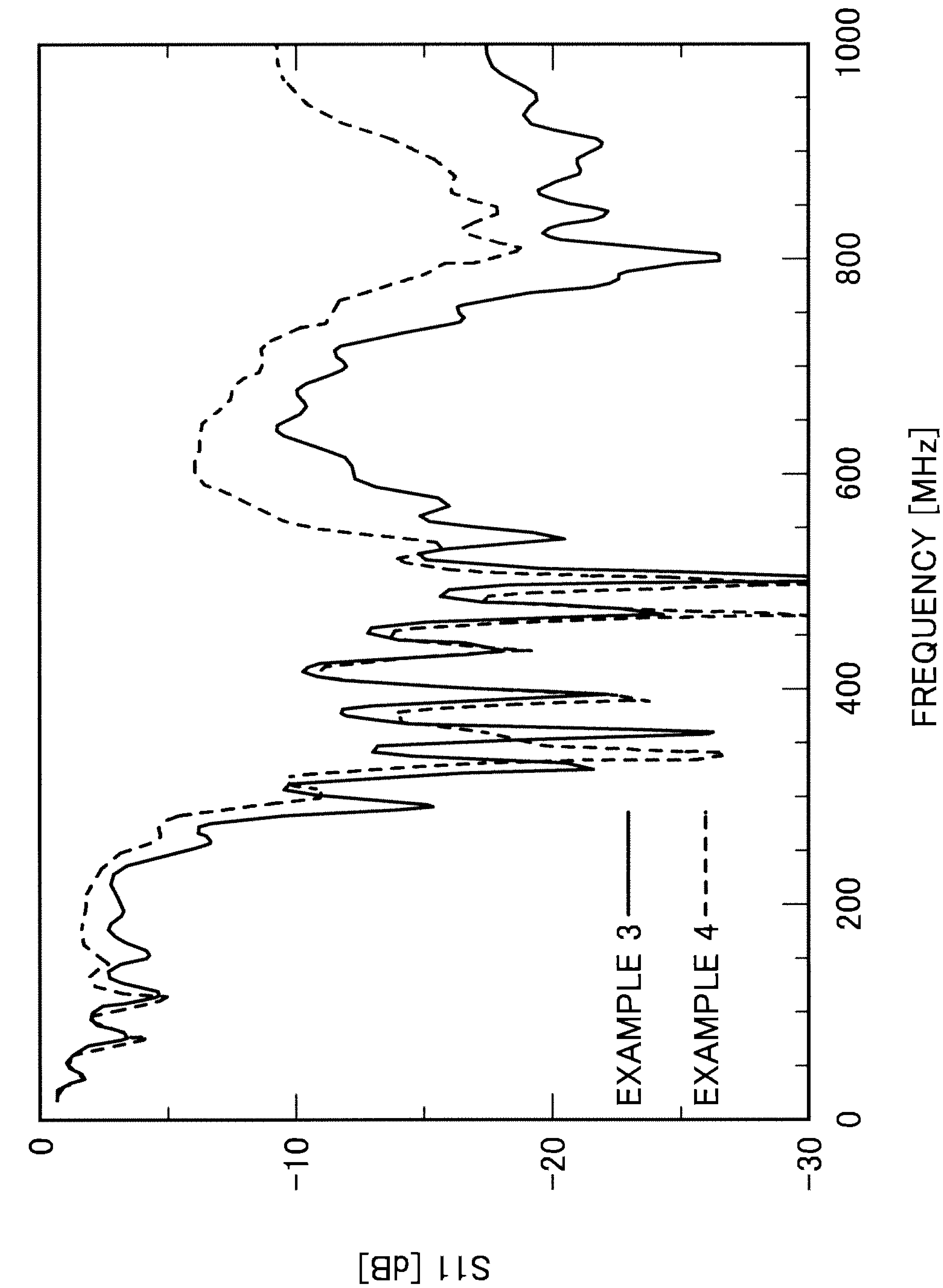

S11 [dB]
0
-10
-20
-30
FREQUENCY [MHz]
0
200
400
600
800
1000
EXAMPLE 1
EXAMPLE 2

FIG.8


S11 [dB]
0
-10
-20
-30
0
200
400
600
800
1000
FREQUENCY [MHz]
EXAMPLE 3
EXAMPLE 4

ANTENNA APPARATUS

CROSS-REFERENCE TO RELATED APPLICATION

This application is a continuation application filed under 35 U.S.C. 111(a) claiming the benefit under 35 U.S.C. 120 and 365(c) of PCT International Application No. PCT/JP2011/079930 filed on Dec. 22, 2011, which is based upon and claims the benefit of priority of Japanese Priority Application No. 2010-293249 filed on Dec. 28, 2010, the entire contents of which are hereby incorporated by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to an antenna apparatus using a clearance between an end portion of a flange of a vehicle body that forms a window opening portion of the vehicle body and a conductive film.

2. Description of the Related Art

FIG. **1** is a cross-sectional view of a vehicle laminated glass including glass plates **1** and **2**, and a conductive film **3** and an intermediate film **4**, sandwiched by the glass plates **1** and **2**. The conductive film **3** is a protection film which suppresses transition of heat waves such as sunlight or the like. When the laminated glass is provided with an antenna conductor **5** for receiving radio waves at a vehicle interior side, there are cases where required reception characteristics cannot be sufficiently obtained as the radio waves coming from the outside of the vehicle are shielded by the conductive film **3**.

To remove such a disadvantage, a window glass is known in which an antenna function is provided by using a conductive film (see, for example, Patent Documents 1, 2 and 3).

PATENT DOCUMENT

[Patent Document 1] Japanese Laid-open Patent Publication No. H6-45817

[Patent Document 2] Japanese Laid-open Patent Publication No. H9-175166

[Patent Document 3] Japanese Laid-open Patent Publication No. 2000-59123

Generally, a window glass is fixed to a flange of a vehicle body that forms a window opening portion of the vehicle body. Patent Documents 1 and 2 disclose a slot antenna using a clearance between an end portion of the flange of the vehicle body and an outer edge of the conductive film. The size of the window opening portion is different in accordance with the kinds of the vehicles. Thus, the perimeter of the clearance between the end portion of the flange of the vehicle body and the outer edge of the conductive film surrounding the conductive film is different in accordance with the kinds of the vehicles. Thus, in a conventional slot antenna, it is necessary to finely adjust the perimeter of the clearance by adjusting the size of the conductive film in order to match the antenna. However, it is a troublesome operation to match the antenna by adjusting the size of the conductive film, which requires a large amount of time and cost.

Further, in the conventional slot antenna, if it is necessary to expand the width (space) of the clearance between the end portion of the flange of the vehicle body and the outer edge of the conductive film in order to obtain a desired antenna gain, the size of the conductive film is reduced. At this time, an area in which the transmission of heat waves such as sunlight or the like cannot be suppressed is increased with respect to the decreasing of the area of conductive film so that the function of the conductive film to suppress the heat waves is decreased.

SUMMARY OF THE INVENTION

The present invention is made in light of the above problems, and provides an antenna apparatus capable of being matched without changing a width of a clearance between an end portion of a flange of the vehicle body and an outer edge of a conductive film as well as capable of improving radiation efficiency and antenna gain.

According to an embodiment, there is provided an antenna apparatus including a glass plate that is fixed to a flange of a vehicle body at a window opening portion of the vehicle body; a dielectric material; a conductive film provided between the glass plate and the dielectric material; and a monopolar feeding portion provided on the dielectric material at a surface opposite to a glass plate side and at a position capable of being capacitively coupled to the conductive film, the antenna apparatus being configured such that a clearance between an end portion of the flange of the vehicle body and an outer edge of the conductive film functions as a slot antenna, the conductive film being provided with a notch having one end as an open end at the outer edge of the conductive film in the vicinity of the feeding portion.

According to the embodiment, the antenna can be matched without changing the width of the clearance between the end portion of the flange of the vehicle body and the outer edge of the conductive film, so that radiation efficiency and antenna gain can be improved.

Note that also arbitrary combinations of the above-described elements, and any changes of expressions in the present invention, made among methods, devices, systems and so forth, are valid as embodiments of the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

Other objects, features and advantages of the present invention will become more apparent from the following detailed description when read in conjunction with the accompanying drawings.

FIG. **1** is a cross-sectional view of a vehicle laminated glass including glass plates **1** and **2**, and a conductive film **3** and an intermediate film **4**, sandwiched by the glass plates **1** and **2**;

FIG. **2** is an exploded view of a vehicle window glass **100** of a first embodiment;

FIG. **3** is an elevation view (seen from a vehicle interior side) illustrating a status in which the vehicle window glass **100** is attached to a flange of a window glass attaching portion at a vehicle body side;

FIG. **4** is a cross-sectional view of the vehicle window glass taken along an A-A line in FIG. **3**;

FIG. **5**A is a view illustrating an embodiment where a conductive film **13** is coated on a glass plate **12**;

FIG. **5**B is a view illustrating an embodiment where a conductive film **13** is coated on a glass plate **11**;

FIG. **5**C is a view illustrating an embodiment where a conductive film **13** between the glass plate **11** and a dielectric material substrate **32** is coated on the glass plate **11**;

FIG. **5**D is a view illustrating an embodiment where a conductive film **13** between the glass plate **11** and the dielectric material substrate **32** is adhered to the plate **11** by an adhesive agent **38**A;

FIG. **6**A is an elevation view illustrating an antenna apparatus including only a notch **24**;

FIG. **6**B is an elevation view illustrating an antenna apparatus including notches **23** and **24**;

FIG. **7** is a view illustrating simulation results of S11; and

FIG. **8** a view illustrating simulation results of S11.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The invention will be described herein with reference to illustrative embodiments. In the drawings for explaining the embodiments, a direction shows a direction in the drawings unless otherwise explained and a reference direction in each of the drawings corresponds to a direction of marks or numerals. Further, a direction in parallel, a direction in perpendicular and the like may include a distortion as long as it does not influence an advantage of the present invention. Further, the present invention may be applicable for a front glass attached to a front portion of a vehicle, a rear glass attached to a rear portion of a vehicle, and a side glass attached to a side portion of a vehicle.

Those skilled in the art will recognize that many alternative embodiments can be accomplished using the teachings of the present invention and that the invention is not limited to the embodiments illustrated for explanatory purposes.

It is to be noted that, in the explanation of the drawings, the same components are given the same reference numerals, and explanations are not repeated.

FIG. **2** is an exploded view of a vehicle window glass **100** composing an antenna apparatus of the embodiment. The vehicle window glass **100** is a laminated glass formed by laminating a glass plate **11**, which is an example of a first glass plate, provided at a vehicle exterior side and a glass plate **12**, which is an example of a second glass plate, provided at a vehicle interior side. FIG. **2** shows elements of the vehicle window glass **100** separated in a direction of a normal line with respect to a surface of the glass plate **11** (or the glass plate **12**).

The vehicle window glass **100** includes the glass plate **11**, the glass plate **12**, an electrode (feeding portion) **16** and a conductive film **13**. Here, the glass plate **12** is used for a dielectric material which sandwiches the conductive film **13** with the glass plate **11**. The glass plate **11** and the glass plate **12** have substantially the same size and outer peripheral ends (**11***a* to **11***d*) of the glass plate **11** and outer peripheral ends (**12***a* to **12***d*) of the glass plate **12** have the same shape, respectively, when seen from a direction (which will be referred to as a "stacked direction" hereinafter) in which the glass plate **12**, the conductive film **13** and the glass plate **11** are stacked.

The electrode **16** is a monopolar feeding portion provided at a surface of the glass plate **12** opposite to a surface at a glass plate **11** side. The monopolar means that only a single feeding portion is provided and no grounded feeding portion is provided. The conductive film **13** is provided between the glass plate **11** and the glass plate **12** so as to overlap a projection of the electrode **16** onto the glass plate **11** side. With this configuration, the electrode **16** capacitively couples with a projected area **21** in the conductive film **13** via the glass plate **12**. The conductive film **13** is provided with notches, each having an open end at an outer edge **13***a* of the conductive film **13** in the vicinity of the projected area **21** of the electrode **16**. FIG. **2** shows a notch **23** provided with an open end **23***a* and a notch **24** provided with an open end **24***a*.

FIG. **3** is an elevation view (seen from the vehicle interior side) illustrating an antenna apparatus which is configured by attaching the vehicle window glass **100** to a window opening portion of a vehicle body. The conductive film **13** is provided such that outer edges **13***a* to **13***d* of the conductive film **13** are positioned inside and spaced away with respect to the outer peripheral edges **11***a* to **11***d* of the glass plate **11** for a predetermined distance, respectively. By providing such a space, corrosion of the conductive film **13** by water immersion or the like from a mating surface of the glass plates **11** and **12** can be prevented. The antenna apparatus is a so-called slot antenna. The clearances **10***a* to **10***d* having a loop shape formed between the end portions **41** to **44** of the flange of the vehicle body, which forms the window opening portion to which the glass plate **12** or the glass plate **11** is attached, and the outer edges **13***a* to **13***d* of the conductive film **13**, function as the slot antenna.

With this structure, while making the electrode **16** as a feeding point, the current flowing along the clearances **10***a* to **10***d* can be varied by adjusting the positions or the lengths of the notches **23** and **24**. Thus, the slot antenna can be easily matched by adjusting embodiments (for example, sizes, shapes or the like) of the notches **23** and **24** formed in the conductive film **13** without varying the gap lengths of the clearances **10***a* to **10***d*, which are the widths between the end portions **41** to **44** of the flange of the vehicle body and the outer edges **13***a* to **13***d* of the conductive film, respectively. Then, as it is unnecessary to change the gap lengths of the clearances **10***a* to **10***d* for matching, the slot antenna can be easily matched while the area of the conductive film **13** for suppressing transmission of heat waves such as sunlight or the like is retained to be larger. Further, compared with a case when the notch is not formed at the conductive film **13**, the current that flows along the outer edge **13***a* of the conductive film **13** can be suppressed by the notches **23** and **24** so that the radiation efficiency as the slot antenna can be increased and the antenna gain is easily improved.

The present embodiment is further explained in detail. The vehicle window glass **100** shown in FIG. **2** has a stacked structure in which the conductive film **13** is provided between the glass plate **11** and the glass plate **12** in a layered manner.

There is provided an intermediate film **14**A between the glass plate **11** and the conductive film **13**. There is provided an intermediate film **14**B between the conductive film **13** and the glass plate **12**. The glass plate **11** and the conductive film **13** are bonded by the intermediate film **14**A, and the conductive film **13** and the glass plate **12** are bonded by the intermediate film **14**B. The intermediate films **14**A and **14**B are, for example, thermo plastic polyvinyl butyral. The relative dielectric constant $\in r$ of the intermediate films **14**A and **14**B may be more than or equal to 2.8 and less than or equal to 3.0, which is a general relative dielectric constant of an intermediate film of a laminated glass.

The glass plates **11** and **12** are transparent dielectric plates, respectively. Further, alternatively, one of the glass plates **11** and **12** may be translucent, or both of the glass plates **11** and **12** may be translucent.

The conductive film **13** is a conductive heat wave reflection film capable of reflecting heat waves coming from the outside. The conductive film **13** is transparent or translucent. The conductive film **13** may be a conductive film formed on a surface of a polyethylene terephthalate film, for example, or a conductive film formed on a surface of the glass plate

(**11** or **12**) as shown in FIG. **5**A to **5**C. Further, as shown in FIG. **5**D, the conductive film **13** may be adhered to a surface of the glass plate **11** by an adhesive agent **38**A. As shown in FIGS. **2** and **3**, the conductive film **13** is provided with the notch **23** having the open end **23***a* at the outer edge **13***a* of the conductive film **13** and the notch **24** having the open end **24***a* at the outer edge **13***a*, which is the same end as that of the open end **23***a* of the notch **23**.

As shown in FIG. **2** and FIG. **3**, the notch **23** is formed from the outer edge **13***a* of the conductive film **13** toward inside. The outer edge **13***a* is one of outer edges of the conductive film **13**. The notch **23** is formed by removing the conductive film **13** from the open end **23***a* to a front end portion **23***b* in a line shape. Similar to the notch **23**, the notch **24** is formed by removing the conductive film **13** from the open end **24***a* to a front end portion **24***b* in a line shape. The front end portions **23***b* and **24***b* are end portions not opened at the outer edges (**13***a* to **13***d*) of the conductive film **13**.

As shown in FIG. **2**, the electrode **16** is positioned at an opposite side to the position of the conductive film **13** while interposing the glass plate **12** therebetween. The electrode **16** is positioned at a surface of the glass plate **12** at the vehicle interior side (in other words, a surface of the glass plate **12** opposite to a surface facing the conductive film **13**) in an exposed manner such that the projected area **21** of the electrode **16**, projected on the conductive film **13** from the stacked direction of the glass plates or the like, is positioned inside the outer edge **13***a* of the conductive film **13**.

Here, the projected area **21** of the electrode **16** may be positioned in an area between the outer edge **13***a* of the conductive film on which the open ends **23***a* and **24***a* are provided and an interface line which is parallel to the outer edge **13***a* and passes the front end portions **23***b* and **24***b* opposite to the open ends **23***a* and **24***a*, respectively. In other words, when the projected area **21** of the electrode **16** is positioned at a side of the open ends **23***a* and **24***a* rather than that of the front end portions **23***b* and **24***b* of the notches **23** and **24**, respectively, there is an advantage in that the antenna can be easily matched. Further, in a view point of easily adjusting the matching of the antenna, the number of notches formed in the vicinity of the electrode **16** is not limited to two, but may be one or three or more. By providing a plurality of the notches in the vicinity of the electrode **16**, the radiation efficiency of the antenna can be improved in addition to making it easy to adjust matching. Specifically, as shown in the drawings, the electrode **16** may be provided between the two notches.

The embodiments (shapes, sizes or the like) of the electrode **16** and the notches **23** and **24** may be determined to satisfy a required value of antenna gain necessary for receiving radio waves that the antenna is to receive. For example, when the frequency band that the antenna is to receive is digital terrestrial television broadcasting band 470 to 710 MHz, the electrode **16** and the notches **23** and **24** are formed to be adaptable for receiving radio waves of the digital terrestrial television broadcasting band 470 to 710 MHz.

When it is assumed that the wavelength in the air at the center frequency of a predetermined frequency band received by the present antenna apparatus is $\lambda 0$, the glass shortening coefficient of wavelength is k (here, k=0.64) and $\lambda g=\lambda 0 \cdot k$, the minimum distance between the center of the electrode **16** and the center line of the notch **23** in its width direction may be more than or equal to 0.25 λg and less than or equal to λg. With this configuration, a preferable result in improving the antenna gain at the frequency band can be obtained.

For example, in order to improve the antenna gain of the predetermined frequency band whose center frequency is 590 MHz, provided that the speed of the radio wave is 3.0×10^8 m/s, the minimum distance between the center of the electrode **16** and the center line of the notch **23** in its width direction may be adjusted to be more than or equal to 81 mm and less than or equal to 330 mm.

Similarly, the length of the notch **23** from the open end **23***a* to the front end may be more than or equal to 0.25 λg and less than or equal to λg. With this configuration, a preferable result in improving the antenna gain at the frequency band can be obtained.

For example, in order to improve the antenna gain of the predetermined frequency band whose center frequency is 590 MHz, the length of the notch **23** from the open end **23***a* to the front end may be adjusted to be more than or equal to 81 mm and less than or equal to 330 mm.

Further, positions of the electrode **16** and the notches **23** and **24** on the glass plate are not specifically limited as long as they are adaptable for receiving the radio waves of a frequency band that the antenna is to receive. For example, the antenna of the embodiment may be provided in the vicinity of the flange of the vehicle body to which the vehicle window glass is to be attached. As shown in FIG. **3**, it is preferable that the antenna is positioned in the vicinity of the end portion **41** of the flange of the vehicle body at a roof side when considering easiness in matching and improvement of discharging efficiency. Further, the antenna may be provided at a position shifted from the position shown in FIG. **3** rightward or leftward to be closer to the end portion **42** or **44** of the flange of the vehicle body at a pillar side, respectively. Further, the antenna may be provided in the vicinity of the end portion **43** of the flange of the vehicle body at a chassis side.

For a case shown in FIG. **3**, longitudinal directions of the notches **23** and **24** match a direction perpendicular to a side of the end portion **41** or **43** of the flange of the vehicle body. However, the longitudinal directions of the notches **23** and **24** are not necessarily in a perpendicular relationship with the side of the end portion of the flange of the vehicle body (or the outer edge of the conductive film **13**). The angles of the longitudinal directions of the notches **23** and **24** with respect to the side may be more than or equal to 5° or less than 90°, respectively.

An attachment angle of the window glass to the vehicle may be 15 to 90°, specifically, 30 to 90° with respect to a horizontal surface (a level surface) when considering easiness in matching and improvement of radiation efficiency.

The electrode **16** is electrically connected to a signal path of an external signal processing apparatus (for example, an on-vehicle amplifier) via a predetermined conductive member **201**. As the conductive member **201**, for example, a feeding line such as an AV line, a coaxial cable or the like is used. When the AV line is used, the AV line is electrically connected to the electrode **16**. When the coaxial cable is used, an inner conductor of the coaxial cable may be electrically connected to the electrode **16** while an outer conductor of the coaxial cable may be grounded to the vehicle body. Further, a structure in which a connector for electrically connecting a conductive member such as a conductor or the like connected to the signal processing apparatus to the electrode **16** is mounted on the electrode **16** may be adopted. The AV line or the inner conductor of the coaxial cable can be easily attached to the electrode **16** by such a connector. Further, a protruding conductive member may be provided on the electrode **16** such that the protruding conductive member contacts and engages a flange **45** of the vehicle body to which the vehicle window glass **100** is attached.

The shape of the electrode **16** may be determined based on the shape or the like of a mounting surface of the above described conductive member or the connector. For example, the electrode **16** may have a rectangular shape such as foursquare, substantially square, rectangular, substantially rectangular or the like, or a polygonal shape when considering an implementation. The electrode **16** may have a circular shape such as circle, substantially circle, ellipse, substantially ellipse or the like.

The electrode **16** is formed by printing a paste including a conducting metal such as a silver paste or the like on a surface of the glass plate **12** at the vehicle interior side and baking. However, the method of forming the electrode **16** is not limited so. Alternatively, the electrode **16** may be formed by forming a linear portion or film of a conductive material such as copper or the like on the surface of the glass plate **12** at the vehicle interior side, or adhering by an adhesive agent to the glass plate **12**.

Further, a masking film formed at a surface of the glass plate may be provided between the electrode **16** and the glass plate **11** (at a deeper side in FIG. **3**) in order to have the electrode **16** not seen from the vehicle exterior side. For the masking film, ceramics, which is a baked material, such as a black ceramics film or the like may be used. At this time, the electrode **16** which is formed on the masking film cannot be recognized from the vehicle exterior side of the window glass because of the masking film so that the good design of the window glass can be obtained.

FIG. **4** is a cross-sectional view of the vehicle window glass **100** taken along an A-A line in FIG. **3**. The flange **45** of the vehicle body is formed for attaching the vehicle window glass **100** thereto by bending inside from the vehicle body toward the window opening portion. The glass plates **11** and **12** composing the laminated glass are fixed to the flange **45** of the vehicle body by bonding the glass plate **12** to the flange **45** of the vehicle body by the adhesive agent **46** (or a gasket).

As shown in FIG. **6**A and FIG. **6**B, the clearance **10***a*, which functions as the slot antenna, is formed between the end portion **41** of the flange **45** of the vehicle body and the outer edge **13***a* of the conductive film **13**, which is nearest to the end portion **41**. The length of the clearance **10***a* in a direction perpendicular to a direction of a normal line of the conductive film **13** (in other words, the gap length H**1** of the clearance **10***a*) may be less than or equal to 20 mm, and more preferably, less than or equal to 15 mm. With this configuration, an advantage that the antenna is easily matched and the radiation efficiency is improved is obtained. When the gap length H**1** of the clearance **10***a* exceeds 20 mm, it is difficult to match the antenna. Here, the gap length H**1** of the clearance **10***a* may be more than or equal to 1 mm considering precision margin in manufacturing such as attaching the glass plate to the flange of the vehicle body or the like.

FIG. **5**A to FIG. **5**D show variations of the stacked structure of the vehicle window glass that composes the antenna apparatus of the embodiment. FIG. **5**A to FIG. **5**D are cross-sectional views of the vehicle window glass taken along the A-A line in FIG. **3**. As shown in FIG. **4** and FIG. **5**A to FIG. **5**D, the conductive film **13** is provided between the glass plate **11** and a dielectric material (in other words, the glass plate **12** or a dielectric material substrate **32**). The conductive film **13** is in contact with an adhesion film between the glass plate and the dielectric material.

For the case shown in FIG. **4**, FIG. **5**A and FIG. **5**B, the conductive film **13** and the intermediate film **14** (or the intermediate films **14**A and **14**B) are provided between the glass plate **11** and the glass plate **12**. FIG. **4** shows an embodiment in which the conductive film **13** formed in a film form is sandwiched between the intermediate film **14**A that contacts a facing surface of the glass plate **11** facing the glass plate **12** and the intermediate film **14**B that contacts a facing surface of the glass plate **11** facing the glass plate **12**. The conductive film **13** formed in the film form may be formed by coating the conductive film **13** such as by performing vapor deposition of the conductive film **13** on a film. FIG. **5**A shows an embodiment in which the conductive film **13** is coated on the glass plate **12** by performing vapor deposition of the conductive film **13** on the facing surface of the glass plate **12** facing the glass plate **11**. FIG. **5**R shows an embodiment in which the conductive film **13** is coated on the glass plate **11** by performing vapor deposition of the conductive film **13** on the facing surface of the glass plate **11** facing the glass plate **12**.

Further, as shown in FIG. **5**C and FIG. **5**D, the vehicle window glass of the antenna apparatus of the embodiment may not be the laminated glass. At this time, the dielectric material may not have a size the same as that of the glass plate **11** and may be a dielectric material substrate having a size sufficient for the electrode **16** to be formed thereon. For the cases shown in FIG. **5**C and FIG. **5**D, the conductive film **13** is provided between the glass plate **11** and the dielectric material substrate **32**. FIG. **5**C is a view illustrating an embodiment where the conductive film **13** is coated on the glass plate **11** by vapor depositing the conductive film **13** on the facing surface of the glass plate **11** that is facing the dielectric material substrate **32**. The conductive film **13** and the dielectric material substrate **32** are bonded with each other by the adhesive agent **38**. FIG. **5**D is a view illustrating an embodiment where the conductive film **13** is adhered to the facing surface of the glass plate **11** that is facing the dielectric material substrate **32** by the adhesive agent **38**A. The conductive film **13** and the dielectric material substrate **32** are bonded by the adhesive agent **38**B. The dielectric material substrate **32** is a resin substrate provided with the electrode **16**. The dielectric material substrate **32** may be a resin print substrate on which the electrode **16** is printed (for example, a glass epoxy substrate in which a copper foil is attached to FR4).

As can be understood from FIG. **4** and FIG. **5**A to FIG. **5**D, the electrode **16** is provided at the glass plate **12** or the dielectric material substrate **32** to overlap the conductive film **13** when seen from the stacked direction.

Example 1

As shown in FIG. **4**, a window glass, which is a laminated glass obtained by bonding two glass plates **11** and **12**, each having a rectangular shape of 800 mm in a vertical direction and 1400 mm in a lateral direction with a thickness of 2.0 mm, via two intermediate films **14**A and **14**B is assumed. Value calculations are performed on a computer for antenna apparatuses shown in FIG. **6**A (a single notch is provided) and FIG. **6**B (two notches are provided). An electrode **16** is provided at a surface of the glass plate **12** at a vehicle interior side, which is assumed to be at a vehicle interior side, and a conductive film **13** provided with a notch **23** (and a notch **24**) is provided between the two intermediate films **14**A and **14**B. The conductive film **13** has a rectangular shape of 790 mm in the vertical direction and 1390 mm in the lateral direction. Outer edges of the conductive film **13**, all of four, are spaced from outer peripheral ends of the glass plates **11** and **12** for 5 mm, respectively. The electrode **16** is provided such that the center in a left-right direction passes the center of the glass plates in the left-right direction. The flange **45** of the vehicle body is assumed such that infinite conductivities are connected at the end portion **41**, and the window glass is assumed to be a front glass so that a defogger is not provided.

In FIGS. **6**A and **6**B, the size of the parts, other than the above described parts, are as follows where the unit of measure is "mm".

H**1**: 5
H**3**: 0
H**4**: 20
W**1**: 3
W**3**: 20
W**5**: 3

Here, "H**1**" corresponds to the gap length of the clearance **10***a*. "H**3**" indicates an interval between the outer edge of the conductive film and an upper end of the electrode. "H**4**" indicates the length of the electrode in the vertical direction. "W**1**" indicates the width of the notch. "W**2**" indicates an interval between a side end portion of the left notch and a left side portion of the electrode. "W**3**" indicates the width of the electrode in the lateral direction. "W**4**" indicates an interval between a side end portion of the right notch and a left side portion of the electrode. "W**5**" indicates the width of the notch.

Further, it is set as follows.

The relative dielectric constant of the glass plate: 7.0

The thickness of each of the intermediate films: 0.38 mm (15 mil)

The sheet resistance of the conductive film **13**: 2.0Ω

The thickness of the conductive film **13**: 0.01 mm

The thickness of the electrode **16**: 0.01 mm

Normalized impedance: 200Ω

For the antenna apparatuses defined above, values of S11 (return-loss (reflection coefficient)) are calculated for every 5 Hz within a frequency range of 25 to 1000 MHz by an electromagnetic field simulation based on Finite-Difference Time-Domain method (FDTD). For S11, as the value is close to zero, it means that the return-loss is large and the antenna gain becomes small and as the minus values becomes large, it means that the return-loss is small and the antenna gain is large.

FIGS. **7** and **8** show simulation results of S11, respectively. For example 1, a result of an embodiment in FIG. **6**A where "H**2**" is 125 mm and "W**2**" is 113.5 mm is shown. For example 2, a result of an embodiment in FIG. **6**B where "H**2**" is 125 mm and "W**2**" and "W**4**" are 113.5 mm is shown. For example 3, a result of an embodiment in FIG. **6**A where "H**2**" is 187.5 mm and "W**2**" is 176 mm is shown. FIG. **8** also shows a result of an embodiment in FIG. **6**B (example 4) where "H**2**" is 187.5 mm and "W**2**" and "W**4**" are 176 mm.

As shown in FIGS. **7** and **8**, according to the antenna apparatus of the embodiment, frequency bandwidth capable of resonating the antenna can be varied (it means that the antenna is matched) by adjusting the distance (W**2**, W**4**) of the notches from the electrode **16** or the length H**2** of the notches. In other words, for the cases shown in FIG. **7**, the resonance frequency bandwidth is 400 to 800 MHz. Then, as shown in FIG. **8**, the resonance frequency bandwidth can be shifted to 300 to 600 MHz by elongating the distance (W**2**, W**4**) or the length H**2** without changing the gap length H**1** of the clearance **10***a*.

TABLE 1

	300 MHz	400 MHz	500 MHz	UNIT: [dB] 600 MHz
EXAMPLE 1	0.55	2.29	0.69	0.62
EXAMPLE 2	1.22	3.15	1.80	1.78
EXAMPLE 3	0.87	0.08	0.55	0.69
EXAMPLE 4	1.49	0.63	1.89	4.03

Table 1 shows the difference of radiation efficiencies at the respective frequency shown in table 1 for each of the examples 1 to 4. The radiation efficiency is a benchmark of energy conversion efficiency between the antenna and the air.

There are many cases that the characteristics of the antenna depend on a degree of impedance matching in addition to the radiation efficiency. Thus, it is desirable to consider actual gain of the antenna when studying the characteristics in an actual environment. The actual gain is defined by a value obtained by subtracting radiation efficiency η (losses by the dielectric material and conductive material) and mismatching loss (loss originated from impedance mismatching) from directional gain Gd.

Thus, the actual gain is expressed as follows.

$$\text{Actual gain } Gw=(1-\Gamma^2)\times\text{radiation efficiency } \eta\times\text{directional gain } Gd$$

Here, β is reflection coefficient (linear expression of S11). It means that the actual gain includes influences of both the radiation efficiency and S11 (return-loss). Here, it is assumed that S11 (return-loss) is the same and the significance of the antenna characteristics is evaluated based on the difference of radiation efficiencies.

Each of the values expressing the difference of radiation efficiencies in table 1 is a relative value with respect to the radiation efficiency of the structure shown in FIG. **6**A without the notch (only with the electrode **16**). It means that each of the values is normalized so that the radiation efficiency of the structure shown in FIG. **6**A without the notch **24** becomes 0 dB. Thus, when the value is plus, it means that the radiation efficiency is improved compared with the structure without the notch **24**. As shown in table 1, by providing the notch, without changing the gap length H**1** of the clearance **10***a*, the radiation efficiency is improved for the frequencies shown in table 1 compared with the case without the notch. Further, as can be understood from the comparison between the example 1 and the example 2, or between the example 3 and the example 4, the radiation efficiency can be further increased by increasing the number of notches. As the energy is radiated by the notch, the current that flows through the outer edge of the conductive film can be suppressed to improve the antenna gain.

As such, by providing the notch in the vicinity of the electrode, the antenna can be matched without changing the gap length of the clearance between the end portion of the flange of the vehicle body and the outer edge of the conductive film. As a result, as the antenna can be matched by adjusting the notch without changing the size of the conductive film, an area where the transmission of the heat waves cannot be suppressed can be prevented from becoming large. Further, the radiation efficiency can be increased so that the antenna gain can be easily improved.

The present invention may be preferably used for a vehicle antenna that receives, for example, digital terrestrial television broadcasting, analog television broadcasting of UHF band, digital television broadcasting of the USA, digital television broadcasting of European Union regions, or digital television broadcasting of China. In addition, the present invention may be used for FM broadcast band of Japan (76 to 90 MHz), FM broadcast band of the USA (88 to 108 MHz), television VHF band (90 to 108 MHz, 170 to 222 MHz) or a vehicle keyless entry system (300 to 450 MHz).

The present invention may also be used for an 800 MHz band mobile telephone system (810 to 960 MHz), an 1.5 GHz band mobile telephone system (1.429 to 1.501 GHz), a Global Positioning System (GPS: artificial satellite GPS signal 1575.42 MHz) or a Vehicle Information and Communication System (registered trademark) (VICS: 2.5 GHz).

Further, the present invention may also be used for communication of Electronic Toll Collection System (transmit frequency of roadside radio equipment: 5.795 GHz or 5.805 GHz, a received frequency of roadside radio equipment: 5.835 GHz or 5.845 GHz), Dedicated Short Range Communication (DSRC: 915 MHz band, 5.8 GHz band, 60 GHz band), microwave (1 GHz to 3 THz), millimeter wave (30 to 300 GHz) or Satellite Digital Audio Radio Service (SDARS: 2.34 GHz, 2.6 GHz).

Although a preferred embodiment of antenna apparatus has been specifically illustrated and described, it is to be understood that minor modifications may be made therein without departing from the spirit and scope of the invention as defined by the claims.

The present invention is not limited to the specifically disclosed embodiments, and numerous variations and modifications and modifications may be made without departing from the spirit and scope of the present invention.

What is claimed is:

1. An antenna apparatus comprising: a glass plate that is fixed to a flange of a vehicle body at a window opening portion of the vehicle body; a dielectric material; a conductive film provided between the glass plate and the dielectric material; and a monopolar feeding portion provided on the dielectric material at a surface opposite to a glass plate side and at a position capable of being capacitively coupled to the conductive film, the antenna apparatus being configured such that a clearance between an end portion of the flange of the vehicle body and an outer edge of the conductive film functions as a slot antenna, the conductive film being provided with a notch having one end as an open end at the outer edge of the conductive film in the vicinity of the monopolar feeding portion,

the conductive film is positioned to overlap the monopolar feeding portion projected on the glass plate side, and the monopolar feeding portion is capacitively coupled to the conductive film.

2. The antenna apparatus according to claim **1**, wherein the monopolar feeding portion is positioned between the outer edge of the conductive film at which the open end is provided and an interface line that is parallel to the outer edge and passes a front end portion, which is an end of the notch opposite to the open end, of the notch.

3. The antenna apparatus according to claim **1**, wherein the conductive film is provided with a plurality of the notches, and the monopolar feeding portion is positioned between the plurality of notches.

4. The antenna apparatus according to claim **1**, wherein a gap length of the clearance is less than or equal to 20 mm.

5. The antenna apparatus according to claim **1**, wherein the dielectric material is another glass plate different from the glass plate.

6. The antenna apparatus according to claim **5**, further comprising: an intermediate film provided between the glass plate and the other glass plate.

7. The antenna apparatus according to claim **6**, wherein the intermediate film is provided:

between the glass plate and the conductive film;

between the other glass plate and the conductive film; or

between the glass plate and the conductive film, and between the other glass plate and the conductive film.

8. The antenna apparatus according to claim **1**, wherein the dielectric material is a plate or a film object.

* * * * *